Electrical Engineering Department
EE352 Machine I

Single Phase Transformer Done

Home work # 2

1. A 3000/200-V. 50-Hz. 1-phase transformer is built on a core having an effective cross-sectional area of 150 cm^2 and has 80 turns in the low-voltage winding. Calculate
   (a) The value of the maximum flux density in the core.
   (b) The number of turns in the high-voltage winding.

2. A 3300/230-V 50-Hz 1-phase transformer is to be worked at a maximum flux density of 1.2 Wb/m^2 in the core. The effective cross-sectional area of the transformer core is 150 cm^2. Calculate suitable values of primary and secondary turns.

3. A 40-kVA, 3300/240-V. 50-Hz, 1-phase transformer has 660 turns on the primary. Determine
   (a) The number of turns on the secondary.
   (b) The maximum value of flux in the core.
   (c) The approximate value of primary and secondary full-load currents.
   Internal drops in the windings are to be ignored.

4. A double wound, 1-phase transformer is required to step down from 1900 V to 240 V, 50-Hz. It is to have 1.5 V per turn. Calculate the required number of turns on the primary and secondary windings respectively. The peak value of flux density is required to be not more than 1.2 Wb/m^2. Calculate the required cross-sectional area of the steel core if the output is 10 kVA calculate the secondary current.

5. The no-load voltage ratio in a 1-phase. 50-Hz, core-type transformer is 1200/440. Find the number of turns in each winding if the maximum flux is to be 0.075 Wb.

6. A 1-phase transformer has 500 primary and 1200 secondary turns. The net cross-sectional area of the core is 75 cm^2. If the primary winding be connected to a 400-V, 50-Hz supply calculate.
   a) The peak value of flux density in the core.
   b) Voltage induced in the secondary winding.

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H.W # 2 (solution).

Q1 $V_2 = 4.44 f N_2 \phi_{max} = 4.44 f N_2 B_m A$.

① $200 = 4.44 \times 50 \times 80 \times 150 \times 10^{-4} B_m \Rightarrow B_m = \frac{200}{4.44 \times 50 \times 80 \times 15\overline{0}}$

$B_m = 0.75 \ wb/m^2$.

② $\frac{V_1}{V_2} = \frac{N_1}{N_2} \Rightarrow \frac{3000}{200} = \frac{N_1}{80} \Rightarrow N_1 = \frac{80 \times 3000}{200} = 1200$ turn

* ~~~~~ * ~~~~~

Q2 $V_1 = 4.44 \times f \times N_1 \times 1.2 \times 150 \times 10^{-4} = 3300 \longrightarrow ①$

① $V_2 = 4.44 \times f \times N_2 \times 1.2 \times 150 \times 10^{-4} = 230 \longrightarrow ②$

~~② [illegible] ①~~

$V_B \quad N_1 = \frac{3300}{4.44 \times 50 \times 1.2 \times 150 \times 10^{-4}} = 830$ turn.

② $\frac{V_1}{V_2} = \frac{N_1}{N_2} \Rightarrow \frac{830}{N_2} = \frac{3300}{230} \Rightarrow N_2 = 58$ turn.

~~~~~ * ~~~~~ * ~~~~~

Q3 ① $\frac{V_1}{V_2} = \frac{N_1}{N_2} \Rightarrow \frac{3300}{240} = \frac{660}{N_2}$

$N_2 = \frac{660 \times 240}{3300} = 48$ turn.

② $V_1 = 3300 = 4.44 f N_1 \phi_{max} \Rightarrow \phi_{max} = \frac{3300}{4.44 \times 50 \times 660}$

$\phi_{max} = 22.5 mWb$.

③ ~~$\frac{I_1}{I_2} = \frac{N_2}{N_1} \Rightarrow I_1 = \frac{N_2}{N_1} \cdot I_2 = 40 \times 10$~~

$I_1 = I_p = \frac{40 \times 10^3}{3300} = \frac{S}{V} = 12.12 A$

$I_2 = I_s = \frac{40 \times 10^3}{220} = 166.67 A$.

⑥

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H.W # 2 (solution)

$\because 1900/240\,V$, $f = 50\,Hz$, $\frac{V}{N} = 1.5\,Volt$.

①
$\frac{V_1}{N_1} = 1.5 \Rightarrow \frac{1900}{1.5} = N_1 \Rightarrow N_1 = 1267\,turn.$

$\frac{V_2}{N_2} = 1.5 \Rightarrow \frac{240}{1.5} = N_2 = 160\,turn.$

② $\frac{V_1}{N_1} = 4.44 f B_{max} A \Rightarrow A = \frac{V_1/N_1}{4.44 f B_{max}}$

$A = \frac{1.5}{4.44 \times 50 \times 1.2} = 56.30\,cm^2.$

③ $I_2 = \frac{10 \times 10^3\,(VA)}{240\,(V)} = 41.7\,A.$

* * *

Q5 $V_1 = 1200 = 4.44 \times 50 \times 0.075 \times N_1 \Rightarrow N_1 = \frac{1200}{4.44 \times 50 \times 0.075}$

$N_1 = 73\,turn.$

$\frac{N_1}{N_2} = \frac{V_1}{V_2} = \frac{440}{V_2} \Rightarrow N_2 = \frac{N_1 N_2}{V_1} = \frac{73 \times 440}{1200} = 27\,turn.$

* * *

Q6 $N_1 = 500$, $N_2 = 1200$, $A = 75\,cm^2$, $V_2 = 400\,V$, $f = 50\,H$.

① $B_{max} = \frac{400}{4.44 \times 50 \times 75 \times 10^{-4} \times 500} = 0.48\,wb/m^2\,(Tesla).$

② $V_2 = 4.44 \times 50 \times 1200 \times 0.48 \times 75 \times 10^{-4} = 960\,Volt$

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good luck.

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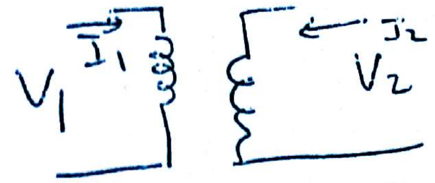
H.W # 3 (Solution)

Q1



$\frac{V_1}{V_2} = \frac{N_1}{N_2} \Rightarrow V_2 = \frac{N_2}{N_1} \cdot V_1 = \frac{23}{300} \cdot 1500 = 115$ Volt.

$I_1 = \frac{S}{V} = \frac{10\times10^3}{1500} = 6.67A.$

$I_2 = \frac{10\times10^3}{115} = 86.95 = 87A.$ ⇒ othermethod to solve I_2.

$I_2 = I_1 \cdot \frac{N_1}{N_2} = \frac{6.67\times300}{23} = 87A.$

$\therefore V_1 = 4.44 f N_1 \phi_{max} \Rightarrow 1500 = 4.44 \times 60 \times 300 \phi_{max}.$

$\phi_{max} = \frac{1500}{60 \times 4.44 \times 300} = \frac{1500}{79920} = 18.76$ mWb.

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$I_1 = \frac{100\times10^3}{3300} = 30.3A, \quad I_2 = \frac{100\times10^3}{400} = 250A.$

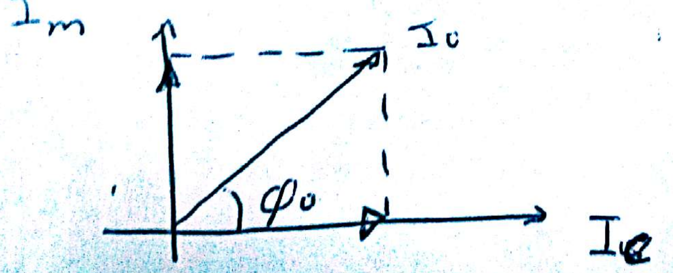
Q2

$V_2 = 4.44 f N_2 \phi_{max} \Rightarrow \phi_{max} = \frac{400}{4.44 \times 50 \times 110} = 16.4$

$\frac{V_1}{V_2} = \frac{N_1}{N_2} \Rightarrow N_1 = \frac{V_1}{V_2} \cdot N_2 = \frac{3300 \times 110}{400} = 907$ turn.

Q3 $V_1 = 230 = 4.44 \times N_1 \times f \times \phi_{max} \Rightarrow \phi_{max} = \frac{230}{4.44 \times 50 \times 200}$

$\phi_{max} = 5.18$ mWb



I_w = iron losses component.

I_m = magnetising current.

I_0

⑨

$I_w = I_0 \cos\phi = 5 \times 0.3 = 1.5$ A..

H.W#3 (solution)

$I_M = \sqrt{I_0^2 - I_c^2}$

$I_M = \sqrt{5^2 - 1.5^2} = 4.77A$. other solution for I_M.

$I_M = I_0 \sin\phi_0 = 5\sin(\cos^{-1} 0.3) = 5\sin 72.542 = 4.77 A$

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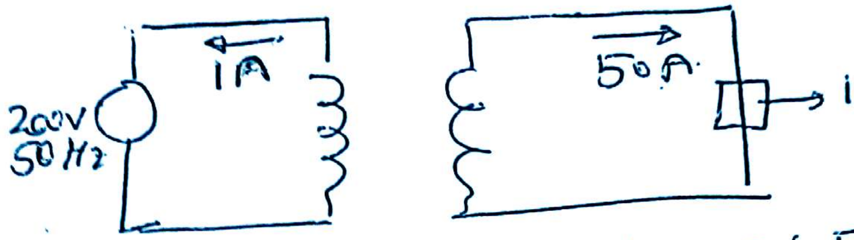
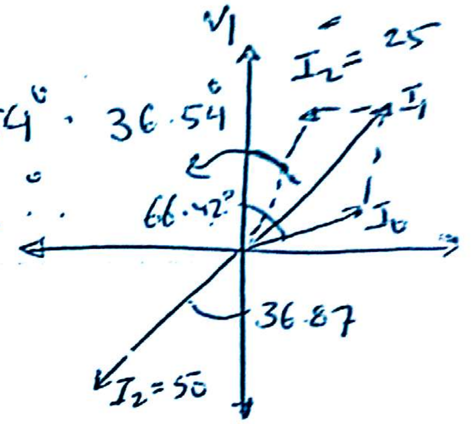
Q4



$\cos\phi_2 = 0.8 \Rightarrow \phi_2 = \cos^{-1}(0.8) = 36.54°$

$\cos\phi_0 = 0.4 \Rightarrow \phi_0 = \cos^{-1}(0.4) = 66.42°$



$K = \frac{1}{2}$.

$\bar{I_2} = KI = 50 \times \frac{1}{2} = 25 A$

secondary current reffered to primary

Angle between I_0 and $\bar{I_2} = 66.42 - 36.54 = 29.88°$

Using parallelogram law ~~of~~ vectors

$I_1 = \sqrt{(1)^2 + (25)^2 + (2 \times 1 \times 25 \times \cos 29.88)} = 25.9A$

* * *

Q5 $N_p = 350t$, $N_s = 38t$, $V_{primary} = 2.2kV$. at No load

① $\frac{V_p}{V_s} = \frac{N_p}{N_s} \Rightarrow V_s = V_p \cdot \frac{N_s}{N_p} = \frac{2200 \times 38}{350} = 239$ turn.

② $I_0 = 5\angle{-\cancel{\phi}_0} \Rightarrow \phi_0 = \cos^{-1} 0.2 = 78.46$ lagging.

$I_0 = 5\angle -78.46°$, $\therefore K = \frac{38}{350} = \frac{V_2}{V_1}$

$\bar{I_2} = K I_2 = \frac{38}{350} \times 200 = 21.714A$.

$\bar{I_2} = 21.714\angle -\phi_2$, $\phi_2 = \cos^{-1} 0.8 = 36.87$ lagging

⑩

HW #3 (Solution)

The primary current $I_1 = I_0 + \bar{I_2}$.

$I_1 = 21.714\angle{-36.87} + 5\angle{-78.46} \Rightarrow 25.65\angle{-44.29^\circ}$.

$I_1 = |I_1|\angle\phi \Rightarrow |I_1| = 25.65A$.

$\phi_g = 44.29 \Rightarrow \cos\phi = \cos \cancel{2}44.29 = 0.715$ lagging

Good luck.

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E352 Electric Machine I

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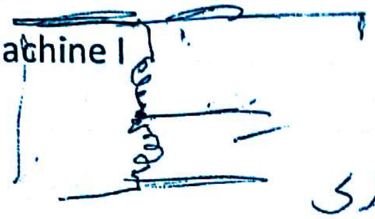
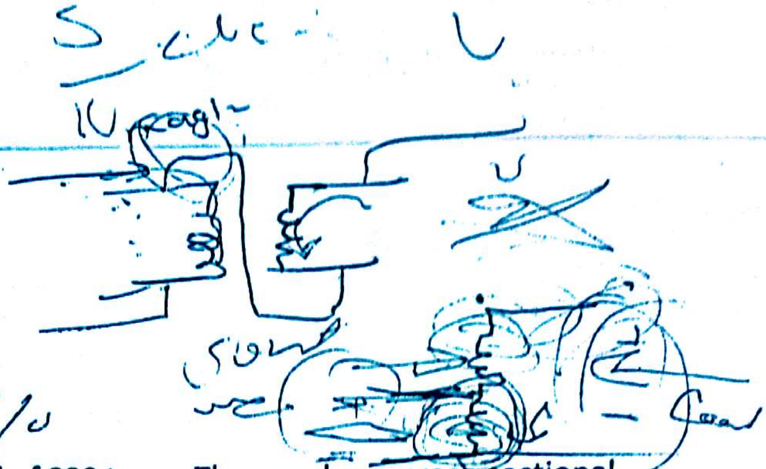
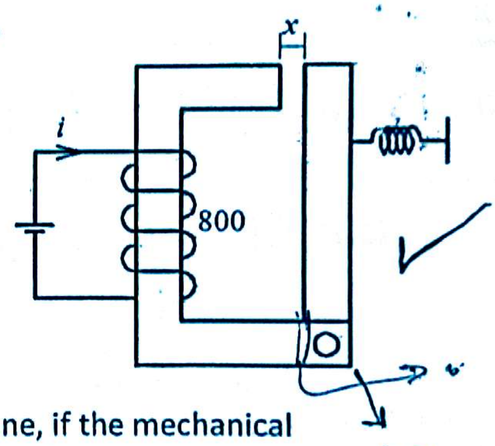




1. An electromagnetic relay has exciting coil of 800 turns. The core has a cross-sectional area of 5 cm x 5 cm. Neglect the reluctance of the core and fringing.
   a. Find the coil inductance if the air gap length is 0.5 cm.
   b. Find the field energy stored for a coil current of 1.25 A.
   c. Coil current remain constant at 1.25 A. find the mechanical energy output based on field energy change when the armature moves to a position for which x = 0.25 cm. Assume slow movement of armature.
   d. Repeat (c) based on force calculation and mechanical displacement.
   e. What will be the change in the mechanical work done, if the mechanical movement is fast, keeping the flux initially constant.

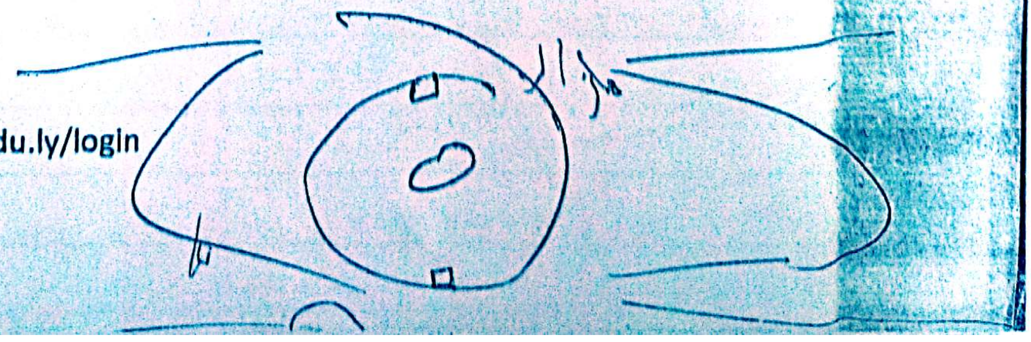


Position

2. A cylindrical rotating machine has the following data
   Stator resistance = 40 Ω Stator self-inductance = 0.16 H
   Rotor resistance = 2 Ω Rotor self-inductance = 0.04+0.02 cos2θ
   Mutual inductance = 0.08 cos θ

   Where θ is the space angle between axes of rotor and stator coils. The rotor revolving at a speed of 100 radian / sec. For is = 10 A (D.C) and ir = 2 A (D.C), obtain an expression for torque and corresponding electrical power.

http://uap5.mtk1.uot.edu.ly/login



H.W # 7   Dr. Grali.

P1

a) $R_c \to \infty \Rightarrow P_c = 0$

$$R_g = \frac{l_g}{\mu_0 A_g} = \frac{0.5\times10^{-2}}{4\pi\times10^{-7}\times5\times5\times10^{-4}} = 1.592\times10^{6}\ \frac{At}{Wb}$$

$$L = \frac{N^2}{R_g} = \frac{(800)^2}{1.592\times10^{6}} = 0.402\ H.$$

b) Field energy stored in magnetic field $= \frac{1}{2} L i^2 = \frac{1}{2}\times0.402\times(1.25)^2$

$= 0.314$ Joule.

c)

$$\therefore W'_{fd} = \frac{1}{2} L(x)\, i^2 = \frac{1}{2}\frac{N^2}{R_g(x)} i^2 = \frac{1}{2}\times\frac{800^2\times4\pi\times10^{-7}\times5\times5\times10^{-4}}{x} i^2$$

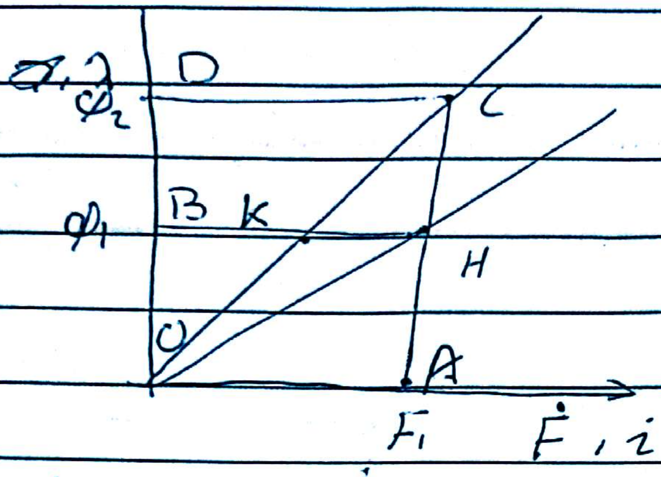
$$W'_{fd} = \frac{1.005\times10^{-3}}{x} i^2$$

Then $F = \dfrac{\partial W'_{fd}}{\partial x} = \left[\dfrac{-1.005\times10^{-3}\ i^2}{x^2}\right] \longrightarrow \textcircled{1}$

F at x = 50 cm $F = \dfrac{-1.005\times10^{-3}\times1.25^2}{(0.5\times10^{-2})^2} = 62.8$ N.W

~~This force has~~ to be balanced by the spring tension.

) the mechanical movement is slow means mmf is constant and the current unchanged (constant)



The electrical Energy input during change over of the operating point From H to C — the area HBDC.

$$\text{Electrical energy} = [\phi_2 - \phi_1] F = \left[\frac{L(x_2) i - L(x_1) i}{\cancel{\Delta x}}\right] \cancel{\Delta x}\, i$$

$$= [L(x_2) - L(x_1)]\, i^2 \cancel{= \int\theta}$$

∴ ~~$L(x_1)$~~ ⇒

$$L(x) = \frac{N^2 \mu_0 A_g}{x}$$

$L(x_1) \Rightarrow \quad x_1 = 0.50$ cm.

$$L(x_1) = \frac{(800)^2 \times 4\pi \times 10^{-7} \times 25 \times 10^{-4}}{0.50 \times 10^{-2}} = 0.402.$$

$L(x_2) \Rightarrow \quad x_2 = 0.25$ cm

$$L(x_2) = \frac{(800)^2 \times 4\pi \times 10^{-7} \times 25 \times 10^{-4}}{0.25 \times 10^{-2}} = 0.804.$$

∴ Electrical energy $= [0.804 - 0.402] \times (1.25)^2 = 0.628$ Joule hen the additional stored energy - [From x_1 to x_2] i^{2}

$$dW_f = \frac{1}{2}\left[L(x_2) - L(x_1)\right] i^2 = \frac{1}{2}\left[0.804 - 0.402\right] 1.25^2$$

$dW_f = 0.314$ Joule.

$dW_e = dW_m + dW_f \Rightarrow dW_m = 0.628 - 0.314 = 0.314$ Joule

he remaning 0.314 Joule is transferred to mechanical from. nd is related to the work done.

This is obtained when the Force on moving member s multiplied by the displament.

$$\int_{x_1}^{x_2} dW_m = 0.314 \text{ Joule}$$

] As in equation (1)'.

$$F(x) = \frac{\left[-1.005 \times 10^{-3} \times (1.25)^2\right]}{x^2}$$

$dW_m = F(x)\, dx$.

$$W_{mech} = \int_{x_1}^{x_2} F(x)\, dx = -\left[1.005 \times 10^{-3} \times (1.25)^2\right] \int_{x_1}^{x_2} x^{-2}\, dx = \left[1.005 \times 10^{-3} \times (1.25)^2\right] \left[\frac{1}{x}\right]$$

$$W_{mech} = 1.005 \times 10^{-3} \times (1.25)^2 \left[\frac{1}{0.25} - \frac{1}{0.5}\right] \times 10^2 = \frac{1.005 \times 1.25 \times 2}{10}$$

$W_{mech} = 0.314$ Joule.

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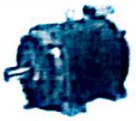
SPRING 2016



HOME WORK FOUR
Dr MUSTAFA AL-REFAI

TRIPOLI UNIVERSITY
FACULTY OF ENGINEERING
ELECTRICAL AND ELECTRONIC DEPARTMENT

EE 352 S 2016
HOME WORK FOUR

PROBLEM 1:

Calculate the percentage voltage drop for a transformer with a percentage resistance of 2.5% and a percentage reactance of 5% of rating 500 kVA when it is delivering 400 kVA at 0.8 p.f. lagging..

PROBLEM 2 :

Obtain the equivalent circuit of a 200/400-V, 50 hz , single phase transformer from the following test data.

$O.C.\ test : 200V, 0.7A, 70W - on\ lv.side$

$S.C.test : 15V, 10A, 85W - on\ hv.side$

Calculate the secondary voltage when delivering 5 Kw at 0.8 p.f. lagging, the primary voltage being 200V.

PROBLEM 3 :

Consider a 20 kVA, 2200/220V, 50Hz transformer. The O.C./S.C. test results are as follows:

$O.C.test : 220V, 4.2A, 148W (l.v.side)$

$S.C.test : 86V, 10.5A, 360W (h.v.side)$

Determine the regulation at 0.8 p.f. lagging and at full load. What is the p.f. on short-circuit?

PROBLEM 4 :

A 250/500-V transformer gave the following results test results:

$S.C. : with\ low-voltage\ winding S.C. : 20V; 12A; 100W$

$O.C.test : 250V, 1A, 80W\ on low-voltage\ side.$

Determine the circuit constants; insert these on the equivalent circuit diagram and calculate applied voltage and efficiency when the output is10A at 500 volt and 0.8 p.f. lagging.

PROBLEM 5 :

A short circuit test when performed on the low voltage side of a 10Kva, 2000/400V single phase transformer gave the following data : $60V, 4A, 100W$ If the Lowe voltage side is delivering f.l. current at 0.8 p.f. lag and at 400V, find the voltage applied to the high voltage side.

PROBLEM 6 :

A 11000/230 V, 150kVA, 1-phase, 50-Hz, transformer has core loss of 1.4 kW and F.L. cu loss of 1.6 kW. Determine.

(i) The k VA a load for max efficiency and value of max, efficiency at unity p.f.

(ii) The efficiency at half F.L. 0.8. p.f leading

SOLUTION OF PROBLEM 1:

$$\% \text{ drop} = \frac{(\%R)I\cos\phi}{I_f} + \frac{(\%X)I\sin\phi}{I_f}$$

where I_f is the full-load current and I the actual current .

$$\therefore \qquad \%\text{drop} = \frac{(\%R)kW}{kVA\,rating} + \frac{(\%X)kVAR}{kVAR\,rating}$$

In the present case , k W = $400\times0.8 = 320$ and k VA = $400\times0.6 = 240$

$$\therefore \qquad \% \text{ drop} = \frac{2.5\times320}{500} + \frac{5\times240}{500} = 4\ \%$$

SOLUTION OF PROBLEM 2 :

From O.C. Test

$$V_1 I_0 \cos\phi_0 = W_0$$

$$\therefore \qquad 200\times0.7\times\cos\phi_0 = 70$$

$\cos\phi_0 = 0.5$ and $\sin\phi_0 = 0.866$

$I_w = I_0\cos\phi_0 = 0.7\times0.5 = 0.35\ A$

$I_\mu = I_0\sin\phi_0 = 0.7\times0.866 = 0.606\ A$

$R_0 = V_1/I_w = 200/0.35 = 571.4\ \Omega$

$X_0 = V_1/I_\mu = 200/0.606 = 330\ \Omega$

As shown in Fig . 30.48 , these values refer to primary i.e. low – voltage side .

From S.C. Test

It may be noted that in this test , instruments have been placed in the secondary i.e. high – voltage winding whereas the low – voltage winding i.e. primary has been short - circuit .

Now , as shown in Art . 30.22

$$Z_{02} = V_{SC}/I_2 = 15/10 = 1.5\Omega \ ; \qquad K = 400/200 = 2$$

$$Z_{01} = Z_{02}/K^2 = 1.5/4 = 0.375\Omega$$

Also $\quad I_2^2 R_{02} = W \quad ; \quad R_{02} = 85/100 = 0.85\Omega; \quad R_{01} = R_{02}/K^2 = 0.85/4 = 0.21\ \Omega$

$$X_{01} = \sqrt{Z_{01}^2 - R_{01}^2} = \sqrt{0.375^2 - 0.21^2} = 0.31\Omega$$

Output k VA $= 5/0.8$; Output current $I_2 = 5000/0.8\times400 = 15.6\ A$

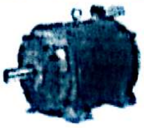
This value of I_2 is approximate because V_2 (which is to be calculated as yet) has been taken equal to 400 V (which , in fact , is equal to E_2 or ${}_0V_2$) .

Now , $\quad Z_{02} = 1.5\Omega, \quad R_{02} = 0.85\ \Omega \qquad \therefore X_{02} = \sqrt{1.5^2 - 0.85^2} = 1.24\Omega$

Total transformer drop as referred to secondary

$$= I_2(R_{02}\cos\phi_2 + X_{02}\sin\phi_2) = 15.6(0.85\times0.8 + 1.24\times0.6) = 22.2\ \text{V}$$

$$\therefore \qquad V_2 = 400 - 22.2 = \mathbf{377.8\ V}$$



SOLUTION OF PROBLEM 3 :

It may be noted that O.C. data is not required in this question for finding the regulation Since during S.C. test , instruments have been placed on the h.v. side i.e. primary side .

$\therefore \quad Z_{01} = 86/10.5 = 8.19\Omega \quad ; \quad R_{01} = 360/10.5^2 = 3.26\Omega\,;$

$$X_{01} = \sqrt{8.19^2 - 3.26^2} = 7.5\Omega.$$

F.L. primary current , $I_1 = 20{,}000/2200 = 9.09\,A$

Total voltage drop as referred to primary = $I_1(R_{01}\cos\phi + X_{01}\sin\phi)$

Drop = $9.09(326\times 0.8 + 7.5\times 0.6) = 64.6\,\text{V}$

% age regn . = $64.6\times 100/2200 = 2.9\%$, p.f. on short – circuit = $R_{01}/Z_{01} = 3.26/8.19 = 0.4$

SOLUTION OF PROBLEM 4 :

Open – circuit Test :

$$V_1 I_0 \cos\phi_0 = 80 \qquad \therefore \quad \cos\phi_0 = 80/250\times I = 0.32$$

$$I_w = I_0\cos\phi_0 = I\times 0.32 = 0.32\,A, \qquad I_\mu = \sqrt{(1^2 - 0.32^2)} = 0.95\,A$$

$$R_0 = V_1/I_w = 250/0.32 = 781.3\Omega \quad , \quad X_0 = V_1/I_\mu = 250/0.95 = 263.8\Omega$$

Short – circuit Test :

As the primary is short – circuited , all values refer to secondary winding .

$$\therefore \qquad R_{02} = \frac{short-crcuit\ power}{F.L.\sec ondary\,current} = \frac{100}{12^2} = 0.694\Omega$$

$$Z_{02} = 20/12 = 1.667\Omega \quad ; \quad X_{02} = \sqrt{(1.667^2 - 0.694^2)} = 1.518\Omega$$

As R_0 and X_0 refer to primary , hence we will transfer these values to primary with the help of transformation ratio .

$K = 500/250 = 2 \qquad \therefore R_{01} = R_{02}/K^2 = 0.694/4 = 0.174\Omega$

$X_{01} = X_{02}/K^2 = 1.518/4 = 0.38\Omega \quad ; \quad Z_{01} = Z_{02}/K^2 = 1.667/4 = 0.417\Omega$

The equivalent circuit is shown in Fig 30.53 .

Efficiency

Total Cu loss = $I_2{}^2 R_{02} = 100\times 0.694 = 69.4$ W; Iron loss = 80 W

Total loss = 69.4+80 = 149.4 W $\qquad \therefore \eta = \dfrac{5000\times 0.8\times 100}{4000 + 149.4} =$ **96.42 %**

The applied voltage V_1' is the vector sum of V_1 and $I_1 Z_{01}$ as shown in Fig . 30.54.

$I_1 = 20\,A \quad ; \quad I_1 R_{01} = 20\times 0.174 = 3.84\ V \quad ; \quad I_1 X_{01} = 20\times 0.38 = 7.6\text{V}$

Neglecting the angle between V_1 and V_1' , we have

$$V_1'^2 = OC^2 = ON^2 + NC^2 = (OM + MN)^2 + (NB + BC)^2$$
$$= (250\times 0.8 + 3.48)^2 + (250\times 0.6 + 7.6)^2$$

ELECTRICAL MACHINE I
SPRING 2016

HOME WORK FIVE
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ELECTRICAL AND ELECTRONIC DEPARTMENT

EE 352 S 2016
HOME WORK FIVE

PROBLEM 1:

The primary and secondary voltages of an auto-transformer are 500 V and 400 V respectively. Show with the aid of a diagram, the current distribution in the winding when the secondary current is 100 A and calculate the economy of Cu in this particular case.

PROBLEM 2 :

Determine the core area , the number of turns and the position of the tapping point for a 500-kVA , 50-Hz , single –phase , 6,600/5,000-V auto-transformer , assuming the following approximate values : e.m.f. per turn 8V . Maximum flux density 1.3 Wb/m^2 .

PROBLEM 3 :

For the 20-kVA, 2400/240-V two-winding step-down transformer, (a) connected as an auto – transformer with additive polarity (d) compute

(i) Original current capacity of HV – winding.
(ii) Original current capacity of LV winding.
(iii) K VA rating of auto –transformer using current capacity of LV winding as calculated in (ii) above .
(iv) Per cent increase in k VA capacity of auto – transformer as compared to original two-winding transformer .
(v) Values of I_1 and I_c (d) from value of I_2 used in (iii) above.
(vi) Per cent over load of 2400-V winding when used as an auto-transformer.
(vii) Comment on the results obtained.

PROBLEM 4 :

A 3-phase, 6,600/415-V, 2,000-k VA transformer has a per unit resistance of 0.02 and a per unit leakage reactance of 0.1. Calculate the Cu loss and regulation at full-load 0.8 p.f. lag.

PROBLEM 5 :

A 120-k VA, 6,000/400-V, Y/Y, 3-ph, 50- Hz transformer has an iron loss of 1,600 W. The maximum efficiency occurs at ¾ full loads.

Find the efficiencies of the transformer at

(i) full-load and 0.8 power factor (ii) half-load and unity power factor.
(iii) The maximum efficiency.

PROBLEM 6 :

A 3-phase transformer, ratio 33/6.6-k VA, Δ / Y , 2-MVA has a primary resistance of 8Ω per phase and a secondary resistance of 0.08 ohm per phase . The percentage impedance is 7%. Calculate the secondary voltage with rated primary voltage and hence the regulation for full-load 0.75 p.f. lagging conditions.

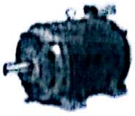
PROBLEM 7:

A 3-phase transformer has its primary connected in Δ and it's secondary in Y. It has an equivalent resistance of 1% and an equivalent reactance of 6%. The primary applied voltage is 6,600 V. What must be the ratio of transformation in order that it will deliver 4,800 V at full-load current and 0.8 power factor (lag).

PROBLEM 8:

A 2000-k VA, 6,600/400-V, 3-phase transformer is delta – connected on the high voltage side and star – connected on the low – voltage side. Determine its % resistance and % reactance drops, % efficiency and % regulation on full load 0.8 p.f. leading given the following data:

S.C. test; H.V. data: 400 V, 175 A and 17 k W
O.C. test; L.V. data: 400 V, 150 A and 15 k W



SOLUTION OF PROBLEM 1:

$K = V_2 / V_1 = 400/500 = 0.8$

$\therefore \quad I_1 = KI_2 = 0.8\times 100 = 80A$

The current distribution

Saving = $KW_0 = 0.8W_0 - Art.30.33$

$\therefore$ Percentage saiving = $0.8\times 100 = 80.$

SOLUTION OF PROBLEM 2 :

$E = 4.44 f\Phi_m N$ volt

$$\Phi_m = \frac{E/N}{4.44f} = \frac{8}{4.44\times 50} = 0.03604 \text{ Wb}$$

Core area = 0.03604/1.3 = 0.0277 m ^{2} = 277 cm ^{2}
Turns of h.v. side = 6600/8 = 825 ; Turns of l.v. side = 5000/8 = 625
Hence, tapping should be 200 turns from high voltage end or 625 turns from the common end.

SOLUTION OF PROBLEM 3 :

(i) $I_1 = 20\times 10^3 / 2400 = 8.33$ A

(ii) $I_2 = I_1 / K = 8.33\times 10 = 83.3$ A

(iii) k VA rating of auto-transformer $V_2 I_2 = 2640\times 83.3\times 10^{-3} = 220$ k VA

(iv) per cent increase in k VA rating = $\dfrac{220}{20}\times 100 = 1100\%$

(v) $I_1 = 220\times 10^3 / 2400 = 91.7$ A , $I_c = I_1 - I_2 = 91.7 - 83.3 = 8.4$ A

(vi) Per cent overload of 2400 V winding = $8.4\times 100/8.33 = 100.8\%$

(viii) As an auto – transformer, the k VA has increased tremendously to 1100% of its original value with LV coil at its rated current capacity and HV coil at negligible overload i.e. 1.008 × rated load .

SOLUTION OF PROBLEM 4 :

As seen, % R = % Cu loss = $\dfrac{Culoss}{VA}\times 100$

Now, %R = 0.02 × $100 = 2\%$ $\quad \therefore \; 2 = \dfrac{Culoss}{2,000}\times 100 \quad \therefore$ Cu loss = 40 kW

Now, percentage leakage reactance =

regn . = $v_r \cos\phi + v_x \sin\phi = 2\times 0.8 + 10\times 0.6 = 7.6\%$

SOLUTION OF PROBLEM 5 :

Since maximum efficiency occurs at ¾ full-load, Cu loss at ¾ full-load equals iron of loss of 1,600 W .

Cu loss at ¾ F.L. = 1,600 W; Cu loss at F.L. = $1,600\times (4/3)^2 = 2,845$ W

(i) F.L. output at 0.8 p.f. = $120\times 0.8 = 96$ k W =96,000 W
Total loss = 1,600+ 2,845= 4,445 W

$$\therefore \quad \eta = \frac{96,000}{100,445}\times 100 = 95.57\%$$

(ii) Cu loss at ½ full-load = $(1/2)^2\times 2,845 = 710W$
Total loss = 710+1,600=2310 W

Output at ½ F.L. and u.p.f. is = 60 k W = 60,000 W ; $\eta = \frac{60,000}{62,310} \times 100 = 96.3\%$

(iii) Maximum efficiency occurs at ¾ full-load when iron loss equals Cu loss .

Total loss = $2 \times 1,600 = 3,200W$

Output at u.p.f. = $(3/4) \times 120 = 90$ k W =90,000 W

Input = 90,000+3,200= 93,200 W $\therefore \eta = \frac{90,000}{93,200} \times 100 = 96.57\%$

SOLUTION OF PROBLEM 6 :

F.L. secondary current = $\frac{2 \times 10^6}{\sqrt{3} \times 6.6 \times 10^3} = 175$ A

$K = 6.6/\sqrt{3} \times 33 = 1/8.65; R_{02} = 0.08 + 8/8.65^2 = 0.1867\Omega$ per phase

Now , secondary impeadance drop per phase = $\frac{7}{100} \times \frac{6,600}{\sqrt{3}} = 266.7V$

$\therefore Z_{02} = 266.7/175 = 1.523\Omega$ per phase

$X_{02} = \sqrt{Z_{02}^2 - R_{02}^2} = \sqrt{1.523^2 - 0.1867^2} = 1.51\Omega$/phase

Drop per phase = $I_2(R_{02}\cos\phi + X_{02}\sin\phi) = 175(0.1867 \times 0.75 + 1.51 \times 0.66) = 200V$

Secondary voltage/phase = $6,600/\sqrt{3} = 3,810V \quad \therefore V_2 = 3,810 - 200 = 3,610V$

$\therefore$ secondary line voltage $= 36,10 \times \sqrt{3} = 6,250$ V

% regn.= $200 \times 100/3,810 = 5.23\%$

SOLUTION OF PROBLEM 7 :

Percentage regulation = $v_r \cos\phi + v_x \sin\phi = 1 \times 0.8 + 6 \times 0.6 = 4.4\%$

Induced secondary e.m.f. (line value)
= 4,800 +4.4 % of 4,800 = 5,010 V

Secondary phase voltage = $5,010/\sqrt{3} = 2,890$ V

Transformation ratio
$K = 2,890/6,600 = 0.437$.

SOLUTION OF PROBLEM 8 :

From S.C. test data , we have

Primary voltage / phase= $400/\sqrt{3} = 231$ V ;Primary current /phase = $175/\sqrt{3} = 100A$

$\therefore Z_{10} = 231/100 = 2.31\Omega$

Now $I_1^2 R_{01} = 17,000/3$ or $R_{01} = 0.567\Omega; X_{01} = \sqrt{2.31^2 - 0.567^2} = 2.24\Omega$

$$\%R = \frac{I_1 R_{01}}{V_1} \times 100 = \frac{100 \times 0.567}{6.600} \times 100 = 0.86$$

$$\%X = \frac{I_1 X_{01}}{V_1} \times 100 = \frac{100 \times 2.24}{6,600} = 100 = 3.4$$

%regn. = $v_r \cos\phi - v_x \sin\phi = 0.86 \times 0.8 - 3.4 \times 0.6 = -1.34\%$

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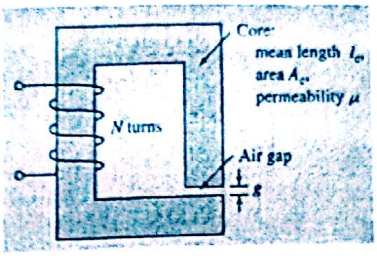

Fig.1

PROBLEM 1:

A magnetic circuit with a single air gap is shown in **Fig.1**. The core dimensions are:

Cross-sectional area $A_c = 1.8 \times 10^{-3}$ m^2
Mean core length $l_c = 0.6$ m
Gap length $g = 2.3 \times 10^{-3}$ m
$N = 83$ turns

PROBLEM 3:

Assume that the core is of infinite permeability ($\mu \rightarrow \infty$) and neglect the effects of fringing fields at the air gap and leakage flux. (a) Calculate the reluctance of the core R_c and that of the gap R_g. For a current of $i = 1.5$ A, calculate (b) the total flux ϕ, (c) the flux linkages λ of the coil, and (d) the coil inductance L.

PROBLEM 2:

Consider the magnetic circuit of **Fig..1** with the dimensions of **Problem 1**.Assuming infinite core permeability, calculate (a) the number of turns required to achieve an inductance of 12 mH and (b) the inductor current which will result in a core flux density of 1.0 T.

PROBLEM 3:

The inductor of Fig.2. has the following dimensions:

$A_c = 1.0$ cm^2
$l_c = 15$ cm
$g = 0.8$ mm
$N = 480$ turns

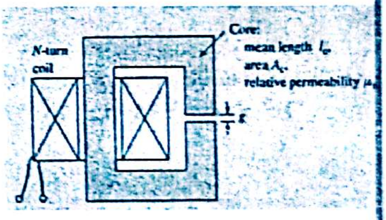

Fig.2.

Neglecting leakage and fringing and assuming $\mu_r = 1000$, calculate the inductance.

PROBLEM 4:

The inductor of Problem 1.13 is to be operated from a 60-Hz voltage source. (a) Assuming negligible coil resistance, calculate the rms inductor voltage corresponding to a peak core flux density of 1.5 T. (b) Under this operating condition, calculate the rms current and the peak stored energy.

PROBLEM 5:

A square voltage wave having a fundamental frequency of 60 Hz and equal positive and negative half cycles of amplitude E is applied to a 1000-turn winding surrounding a closed iron core of 1.25×10^{-3}m^2 cross section. Neglect both the winding resistance and any effects of leakage flux.

(a) Sketch the voltage, the winding flux linkage, and the core flux as a function of time.

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(b) (b) Find the maximum permissible value of E if the maximum flux density is not to exceed 1.15 T.

PROBLEM 6.

A laminated soft iron of relative permeability 1000 has a mean circumference of 800 mm and a cross-section area 500 mm^2 . A radial air-gap of 1 mm width is cut in the ring which is wound with 1000 turns . Calculate the current required to produce on air –gap flux of 0.5mWb if leakage factor is 1.2 and stacking factor 0.9 . Neglect fringing .

PROBLEM 7.

A mild steel ring of 30 cm mean circumference has a cross-sectional area of 6 cm^2 and has a winding of 500 turns on it . The ring is cut through at a point so as to provide an air-gap of 1 mm in the magnetic circuit . It is found that a current of 4 A in the winding , produces a flux density of 1 T in the air – gap . Find (i) the relative permeability of the mild steel and (ii) inductance of the winding .

PROBLEM 8.

An iron ring 30 cm mean diameter is made of square iron of 2 cm x 2 cm cross-section and is uniformly wound with 400 turns of wire of 2 mm^2 cross-section. Calculate the value of the self-inductance of the coil. Assume $\mu = 800$

PROBLEM 9.

If a coil of 150 turns is linked with a flux of 0.01 Wb when carrying current of 10 A, calculate the inductance of the coil. If this current is uniformly reversed in 0.01 second, calculate the induced eltromotive force.

PROBLEM 10.

An iron rod, 2 cm in diameter and 20cm long is bent into a closed ring and is wound with 3000 turns of wire. It is found that when a current of 0.5 A is passed through this coil, the flux density in the coil is 0.5 Wb/m^2 Assuming that all the flux is linked with every turn of the coil, what is (a) B/H ratio for the iron b) inductance of the coil ? What voltage would be developed across the coil if the current through the coil is interrupted and the flux in the iron falls to 10% of its former value in 0.001 second ?

PROBLEM 11.

A circuit has 1000 turns enclosing a magnetic circuit 20 cm^2 in section. With 4 A, the flux density is 1.0 Wb/m^2 and with 9 A, it is 1.4 Wb/m^2. Find the mean value of the inductance between these current limits and the induced e.m.f. if the current falls from 9 A to 4 A in 0.05 seconds.

PROBLEM 12.

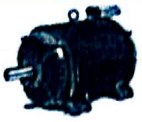
Adirect current of one ampere is passed through a coil of 5000 turns and produces A flux of 0.1 mWb. Assuhnng that whole of this flux threads all the turns, what is the inductance of the coil ? What would be the voltage developed across the coil if the current were interrupted in 10^{-3} second ? What would be the maximum voltage developed across the coil if a capacitor of 10μF were connected across the switch breaking the d.c. supply ?

PROBLEM 13.

(a) A coil of 1000 turns is wound on a torroidal magnetic core having a reluctance of 10^4 AT/Wb. When the coil current is 5 A and is increasing at the rate of 200 A/s, determine.(i) energy stored in the magnetic circuit (ii) voltage applied across the coil Assume coil resistance as zero.

(b) How are your answers affected if the coil resistance is 20Ω.

PROBLEM 14.



Two identical coils X and Y of 1,000 turns each lie in parallel planes such that 80% of flux produced by one coil links with the other. If a current of 5 A flowing in X produces a flux of 0.5 mWb in it, find the mutual inductance between X and Y.

PROBLEM 15.

A long single-layer solenoid has an effective diameter of 10 cm and is wound with 2500 AT meter. There is a small concentrated coil having its plane lying in the centre cross-sectional plane of the solenoid. Calculate the mutual inductance between the two coils in each case if the concentrated coil has 120 turns on an effective diameter of (a) 8 cm and (b) 12 cm.

PROBLEM 16.

A flux of 0.5 mWb is produced by a coil of 900 turns wound on a ring with a current of 3 A in it. Calculate (i) the inductance of the coil (ii) the e.m.f. induced in the coil when a current of 5 A is switched off, assuming the current to fall to zero in I milli second and (iii) the mutual inductance between the coils, if a second coil of 600 turns is uniformly wound over the first coil.

PROBLEM 17.

If a coil of 150 turns is linked with a flux of 0.01 Wb when carrying a current of 10 A; calculate the inductance of the coil. If this current is uniformly reversed in 0.1 second, calculate the induced e.m.f. If a second coil of 100 turns is uniformly wound over the first coil , find the mutual inductance between the coils

PROBLEM 18.

Two coils having 30 and 600 turns respectively are wound side-by-side on a closed iron circuit of area of cross-section 100 sq. cm. and mean length 200 cm. Estimate the mutual inductance between the coils if the relative permeability of the iron is 2000. If a current of zero ampere grows to 20A in a time of 0.02 second in the first coil, find the e.m.f. induced in the second coil.

PROBLEM 19.

Two coils A and B each having 1200 turns are placed near each other. When coil B is open-circuited and coil A carries a current of 5 A, the flux produced by coil A is 0.2 Wb and 30% of this flux links with all the turns of coil B . Determine the voltage induced in coil B on open-circuit when the current in the coil A is changing at the rate of 2 A/s.

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SOLUTION OF PROBLEM 1

(a) $R_c = 0$ since $\mu \to \infty$ $\qquad R_g = \dfrac{g}{\mu_0 A_c} = \dfrac{2.3\times10^{-3}}{4\pi\times10^{-7}\times1.8\times10^{-3}} = 1.017\times10^{6}\ \text{A/Wb}$

(b) $\phi = \dfrac{Ni}{R_c + R_g} = \dfrac{83\times1.5}{1.017\times10^{6}} = 1.224\times10^{-4}\ \text{Wb}$

(c) $\lambda = N\phi = 1.016\times10^{-2}\ \text{Wb}$

(d) $L = \dfrac{\lambda}{i} = \dfrac{1.016\times10^{-2}}{1.5} = 6.773\ \text{mH}$

SOLUTION OF PROBLEM 2

(a) $L = \dfrac{N^2}{R_g} = 12\times10^{-3}\ \text{mH} \quad\Rightarrow\quad N = \sqrt{12\times10^{-3}\times1.017\times10^{6}} = 110.47 \quad\Rightarrow\quad N = 110\ \text{turns}$

(b)

$$B_c = B_g = 1.0\ \text{T} \quad\Rightarrow\quad \phi = B_g A_c = 1.8\times10^{-3}\ \text{Wb}$$

$$i = \frac{\lambda}{L} = \frac{N\phi}{L} = \frac{110\times1.8\times10^{-3}}{12\times10^{-3}} = 16.5\ \text{A}$$

SOLUTION OF PROBLEM 3

$$L = \frac{\lambda}{i} \qquad \lambda = N\phi = NB_cA_c$$

mmf equation: $H_c l_c + H_g l_g = Ni \quad\Rightarrow\quad \dfrac{B_c}{\mu_r\mu_0} l_c + \dfrac{B_g}{\mu_0} g = Ni$

$$B_c = B_g \quad\Rightarrow\quad B_c = \frac{\mu_0 Ni}{g + (l_c/\mu_r)} \quad\Rightarrow\quad L = \frac{\mu_0 N^2 A_c}{g + (l_c/\mu_r)} = \frac{4\pi\times10^{-7}\times480^2\times10^{-4}}{[0.08 + (15/1000)]\times10^{-2}} = 30.477\ \text{mH}$$

SOLUTION OF PROBLEM 4

(a)

$$v(t) = \frac{d\lambda}{dt} = NA_c\frac{dB_c}{dt} \qquad B_c = B_{\max}\sin\omega t \quad\Rightarrow\quad v(t) = \omega NA_cB_{\max}\cos\omega t$$

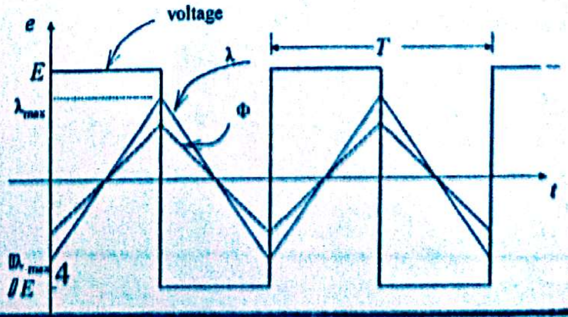
$$\Rightarrow V_{rms} = \frac{1}{\sqrt{2}}\omega NA_cB_{\max} = \frac{1}{\sqrt{2}}(2\pi\times60)\times480\times10^{-4}\times1.5 = 19.2\ \text{V}$$

(b)

$$I_{rms} = \frac{V_{rms}}{\omega L} = 1.67\ \text{A} \qquad W_{peak} = \frac{1}{2}LI_{peak}^2 = \frac{1}{2}\times30.477\times10^{-3}\times(\sqrt{2}\times1.67)^2 = 85.0\ \text{mJ}$$

SOLUTION OF PROBLEM 5

(a)



(b)

$$e(t)=\frac{d\lambda}{dt} \Rightarrow \lambda=\int e(t).dt \Rightarrow E=\frac{\lambda_{max}-(-\lambda_{max})}{T/2}=4f\lambda_{max}=4fN\phi_{max}=4fNA_cB_{max}$$

$$\Rightarrow E=4\times60\times1000\times1.25\times10^{-3}\times1.15=345\text{ V}$$

SOLUTION OF PROBLEM 6.

Total AT reqd. $=\Phi_gS_g+\Phi_iS_i=\dfrac{\Phi_gl_g}{\mu_0A_g}+\dfrac{\Phi_il_i}{\mu_0\mu_rA_iB}$

Now , air –gap flux $\Phi_g=0.5\,\text{mWb}=0.5\times10^{-3}\,\text{Wb}$, $l_g=1\,\text{mm}=1\times10^{-3}\,\text{m}$; $A_g=500\,\text{mm}^2=500\times10^{-6}\,\text{m}^2$

Flux in the iron ring , $\Phi_i=1.2\times0.5\times10^{-3}$ Wb

Net cross-sectional area $=A_i\times$ stacking factor $=500\times10^{-6}\times0.9\,\text{m}^2$

$$\therefore\ \text{total AT reqd.}=\frac{0.5\times10^{-3}\times1\times10^{-3}}{4\pi\times10^{-7}\times500\times10^{-6}}+\frac{1.2\times0.5\times10^{-3}\times800\times10^{-3}}{4\pi\times10^{-7}\times1000\times(0.9\times500\times10^{-6})}=1644$$

$\therefore\quad I=1644/1000=1.64$ A

SOLUTION OF PROBLEM 7.

(a) Steel ring

$H=B/\mu_0\mu_r=1/4\pi\times10^{-7}\times\mu_rAT/m=0.7957\times10^{7}/\mu_rAT/m$

m.m.f. $=H\times l=(0.7957\times10^{7}/\mu_r)\times29.9\times10^{-2}=.2379\times10^{6}/\mu_rAT$

(b) Air-gap

$H=B/\mu_0=1/4\pi\times10^{-7}=0.7957\times10^{6}$ AT/m

m.m.f. reqd . $=H\times1=0.7957\times10^{6}\times(1\times10^{-3})=795.7$ AT

Total m.m.f. $=(0.2379\times10^{6}/\mu_r)+795.7$

Total mmf available $=NI=500\times4=2000$ AT

(i) $\therefore 2000=(0.2379\times10^{6}/\mu_r)+795.7 \qquad \therefore \mu_r=197.5$

(ii) Inductance of the winding $=\dfrac{N\Phi}{I}=\dfrac{NBA}{I}=\dfrac{500\times1\times6\times10^{-4}}{4}=0.075$ H

SOLUTION OF PROBLEM 8.

$L=\mu_0\mu_rAN^2/l$ *here* $N=400;A=2\times2=4cm^2=4\times10^{-4}m^2;l=0.3\pi;\mu_r=800$

$$L=4\pi\times10^{-7}\times800\times4\times10^{-4}\times(400)^2/0.3\pi=68.3mH$$

Note : The cross-section of the wire is not relevant to the given question.

(iii)) Athor Method for L

$$L=\frac{N\Phi}{I} \quad \therefore \quad N\Phi=LI \quad or \quad -N\Phi=-LI$$

Differentiating both sides, we get $-\dfrac{d}{dt}(N\Phi)=-L\dfrac{dI}{dt}$ (assuming L to be constant);

6

$$-N\frac{d\Phi}{dt} = -L\frac{dI}{dt}$$

$-N\dfrac{d\Phi}{dt}$ = self-induced e.m.f. $\therefore$ $e_l = -L\dfrac{dI}{dt}$

If $\dfrac{dI}{dt} = 1$ ampere/second and e, = 1 volt, then $L = 1$ H

Hence, a coil has a self-inductance of one henry if one volt !s induced in it when current through it changes at the rate of one ampere/second.

SOLUTION OF PROBLEM 9.

$$L = \frac{N\Phi}{I} = 150\times 0.01/10 = 0.15H$$

$$Now\ ,\ e_l = L\frac{dI}{dt};\ \ dI = -10-(-10) = 20A$$

$$\therefore \qquad e_l = 0.15\times 20\times 20/0/01 = 300V$$

SOLUTION OF PROBLEM 10.

$$H = \frac{NI}{l} = 3000\times 0.5/0.2 = 7500AT/m \qquad B = 0.5Wb/m^2$$

(a) Now $\dfrac{B}{H} = \dfrac{0.5}{7500} = 6.67\times 10^{-5}H/m\ Also\ \mu_r = B/\mu_0 H = 6.67\times 10^{-5}/4\pi\times 10^{-7} = 53$

(b) $L = \dfrac{N\Phi}{I} = \dfrac{3000\times\pi\times(0.02)^2\times 0.5}{4\times 0.5} = 0.94H$

$e_l = N\dfrac{d\Phi}{DT}Volt\ ;\ d\Phi = 90\%\ of\ orignal\ flux = \dfrac{0.9\times\pi\times(0.02)^2\times 0.5}{4} = 0.45\pi\times 10^{-4}Wb$

dt= 0.001 second $e_l = 3000\times 0.45\pi\times 10^{-4}/0.001 = 424V$ = 3000 x 0.4571 x 10~/0.001 =

424V

Solution of problem 11.

$$L = N\frac{d\Phi}{dt} = N\frac{d}{dt}(BA) = NA\frac{dB}{dt}\,henry = 1000\times 20\times 10^{-4}(1.4-1)/(9-4) = 0.16H$$

Now, $e_l = L\dfrac{dI}{dt};\ dI = (9-4) = 5A, dt = 0.05s$ $\therefore$ $e_l = 0.16\times 5/0.05 = 16V$

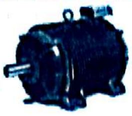
SOLUTION OF PROBLEM 12.

$L = \dfrac{N\Phi}{I} = 5000\times 10^{-4} = 0.5H;$ Induced e.m.f. $= L\dfrac{dI}{dt} = \dfrac{0.5\times 1}{10^{-3}} = 500V$

''' 10"

The energy stored in the coil is $= \dfrac{1}{2}LI^2 = \dfrac{1}{2}\times 0.5\times I^2 = 0.25J$

i



When the capacitor is connected, then the voltage developed would be equal to the p.d. developed across the capacitor plates due to the energy stored in the coil. If V *is* the value of the voltage, then

$$\frac{1}{2}CV^2 = \frac{1}{2}LI^2 ; \frac{1}{2}\times 10\times 10^6 V^2 = 0.25 \; or \; V = 224 volt$$

SOLUTION OF PROBLEM 13.

(a) $L = \frac{N^2}{S} = \frac{1000^2}{10^6} = 1H$

(i) Energy stored $= \frac{1}{2}LI^2 = \frac{1}{2}\times 1\times 5^2 = 12.5J$

(ii) Voltage applied across coil

$= $ self-induced e.m.f. in the coil $= L\frac{dI}{dt} = 1\times 200 = 200V$

(b) Though there would be additional energy loss of $5^2\times 2 = 50$ W over the coil resistance, energy stored in the coil would remain the same. However, voltage across the coil would increase by an amount $= 5\times\ 2 = 10$ V *i.e.* now its value would be 210 V.

SOLUTION OF PROBLEM 14.

Formula used $M = \frac{N_2\Phi_1}{I_1}$; $Flux \; produced \; in \; X = 0.5mWB = 0.5\times 10^{-3} Wb$

Flux linked with $Y = 0.5\times 10^{-3}\times 0.8 = 0.4\times 10^{-3} Wb$; $M = \frac{1000\times 0.4\times 10^{-3}}{5} = 0.08H$

SOLUTION OF PROBLEM 15.

The two cases *(a)* and *(b)* are shown in Fig. 7.12 *(a)* and *(b)* respectively.

(a) Let I_1 be the current flowing through the solenoid. Then

$$B = \mu_0 H = \mu_0 N / l = 2500\mu_0 I_1 \quad Wb/m^2$$

Area of search coil $A_1 = \frac{\pi}{4}\times 8^2\times 10^{-4} = 16\pi\times 10^{-4} m^2$

4

Flux linked with search coil is

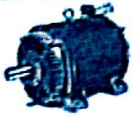
$$\Phi = BA_1 = 2500\mu_0 I_1\times 16\pi\times 10^{-4} = 15.79 I_1\times 10^{-6} Wb$$

$$\therefore \qquad M = \frac{N_2\Phi}{I_1} = \frac{120\times 15.39 I_1\times 10^{-6}}{I_1} = 1.895\times 10^{-3} H$$

(b) 'Since the field strength outside the solenoid is negligible, the effective area of the search coil, in this case, equals the area of the long solenoid.

$$A_2 = \frac{\pi}{4}\times 10^2\times 10^4 = \frac{\pi}{4}\times 10^{-2} m^2 ;$$

$$\Phi = BA_2 = 2500\mu I_1\times\frac{\pi}{4}\times 10^{-2} = 24.68 I_1\times 10^{-6} Wb$$



$$M = \frac{120 \times 24.68 I_1 \times 10^{-6}}{I_1} = 2.962 \times 10^{-3}\ \text{H}$$

SOLUTION OF PROBLEM 16.

(i) Inductance of the first coil = $\frac{N\Phi}{I} = \frac{900 \times 0.5 \times 10^{-3}}{3}$ $=\mathbf{0.15H}$

(ii) e.m.p induced $e_1 = L\frac{di}{dt} = 0.15 \times \frac{(5-0)}{1 \times 10^{-3}} = \mathbf{750}$

(iii) $M\frac{N_2\Phi_1}{I_1} = \frac{600 \times 0.5 \times 10^{-3}}{3} = \mathbf{0.1\ \ H}$

SOLUTION OF PROBLEM 17.

$L_1 = N_1\Phi_1 / I_1 = 150 \times 0.01/10 = \mathbf{0.15\ H}$

$e = L \times di/dt = 0.15 \times [10-(-10)]/0.1 = 1 = \mathbf{30\ V}$

$M = N_2\Phi / I_1 = 100 \times 0.01/10 = \mathbf{0.1\ H}$

SOLUTION OF PROBLEM 18.

Formula used : $M = \frac{N_1 N_2}{l/\mu_0\mu_r A}$ $H, N_1 = 30;\ N_2 = 600;\ A = 100 \times 10^{-4} = 10^{-2}\,m^2, l = 2m$

$\therefore \quad M = \mu_0\mu_r A N_1 N_2 / l = 4\pi \times 10^{-7} \times 2000 \times 10^{-2} \times 30 \times 600/2 = \mathbf{0.226\ H}$

d I_1=20-0 = 20 A ; $dt = 0.02\ s;\ e_M = MdI_1/dt = 0.226 \times 20/0.2 =$ **226 V**

OLUTION OF PROBLEM 19.

Coefficient of mutual induction between the two coils is $M = N_2\Phi_2 / I_1$

Flux linked with coil B is 30 per cent of 0.2 Wb *i.e.* 0.06 Wb

$\therefore \quad M = 1200 \times 0.06/5 = 14.4\ \text{H}$

Mutually-induced e.m.f. in coil *B* is $e_M = MdI_1/dt = 14.4 \times 2$ $= \mathbf{28.8}$ V

ELECTRICAL MACHINES I
FALL - 2013

HOME WORK TWO
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EE 352 F 2013
HOME WORK TWO

PROBLEM 1.

Two identical 750 turn coils A and B lie in parallel planes. A current changing at the rate of 1500 A/s in A induces an e.m.f of 11.25 V in B. Calculate the mutual inductance of the arrangement. If the self-inductance of each coil is 15 mH, calculate the flux produced in coil A per Ampere and the percentage of this flux which links the turns of B.

PROBLEM 2.

Two coils A of 1200 turns and B of 1600 turns, lie in parallel planes so that 60% o flux produced in A links coil B. it is found that a current of 5 A in A produces a flux of 0.6 mWb while the same current in B produces 0.8 mWb. Determine (i) mutual inductance and (ii) coupling coefficient.

PROBLEM 3.

Two magnetically-coupled coils have a mutual inductance of 32 mH. What is the average e.m.f. induced in one, if the current through the other changes from 3 to 15 Ma in 0.004 second? Given that one coil has twice the number of turns in the other, calculate the inductance of each coil. Neglect leakage.

PROBLEM 4.

Two coils, A and B, have self inductances of 120 μ H and 300 μ H respectively. A current of 1A through coil A produces flux linkages of 100 μ Wb turns in coil B. calculate (I) the mutual inductance between the coils (ii) the coupling coefficient and (iii) the average e.m.f. induced in coil B if a current of 1A in coil A is reversed at a uniform rate in 0.1 sec.

PROBLEM 5.

Two coils with a coefficient of coupling of 0.5 between them, are connected in series so as to magnetize (a) in the same direction (b) in the opposite direction. The corresponding values of total inductances are for (a) 1.9 H and for (b) 0.7 H. find the –self – inductances of the tow coils and the mutual inductance between them.

PROBLEM 6.

The combined inductance. Of two coils connected in series is 0.6 H or 0.1 H depending on the relative directions of the currents in the coils. If one of the coils when isolated has a self – inductance of 0.2 **H**, calculate (a) mutual inductance and (b) coupling coefficient.

PROBLEM 7.

Two similar coils have a coupling coefficient of 0.25 When they are connected in series cumulatively, the total inductance is 80 mH: calculate the self inductance of each coil. Also calculate the total inductance when the coils are connected in series differentially.

PROBLEM 8.

Two coils with terminals T_1, T_2 and T_3, T_4 respectively are placed side by side. When measured separately, the inductance of the first coil is 1200 mH and that of the second is 800 mH. With T_2 joined to T_3, the inductance between T_1 and T_4 is 2500 mH. What is the mutual inductance between the two coils? Also determine the inductance between T_1 and T_3 when T_2 is joined to T_4.

PROBLEM 9.

The total inductance of two coils, A and B, when connected in series, is 0.5 H or 0.2 H, depending on the relative directions of the current in the coils. Coil A, when isolated from coil B, has a self-inductance of 0.2 H. Calculate

(a) The mutual inductance between the two coils (b) the self-inductance of coil B

(c) The coupling factor between the coils.

(d) The two possible values of the induced e.m.f. in coil A when the current is decreasing at 1000 A per second in the series circuit.

PROBLEM 10.

Two coils of inductances 4 and 6 Henry are connected in parallel. If their mutual inductance is 3 Henry, calculate the equivalent inductance of the combination if (i) mutual inductance assists the self – inductance (ii) mutual inductance opposes the self- inductance.

PROBLEM 11.

A source which can be represented by a voltage source of 8 V rms in series with an internal resistance of 2 kΩ is connected to a 50-Ω load resistance through an ideal transformer. Calculate the value of turns ratio for which maximum power is supplied to the load and the corresponding load power? Using MATLAB, plot the the power in milliwatts supplied to the load as a function of the transformer ratio, covering ratios from 1.0 to 10.0.

PROBLEM 12.

A 460-V:2400-V transformer has a series leakage reactance of 37.2 Ω as referred to the high-voltage side. A load connected to the low-voltage side is observed to be absorbing 25 kW, unity power factor, and the voltage is measured to be 450 V. Calculate the corresponding voltage and power factor as measured at the high-voltage terminals.

PROBLEM 13.

The resistances and leakage reactances of a 30-kVA, 60-Hz, 2400-V:240-V distribution transformer are

$$R_1 = 0.68\ \Omega \qquad R_2 = 0.0068\ \Omega$$
$$X_{l1} = 7.8\ \Omega \qquad X_{l2} = 0.0780\ \Omega$$

where subscript 1 denotes the 2400-V winding and subscript 2 denotes the 240-V winding. Each quantity is referred to its own side of the transformer.

a. Draw the equivalent circuit referred to (i) the high- and (ii) the low-voltage sides. Label the impedances numerically.
b. Consider the transformer to deliver its rated kVA to a load on the low-voltage side with 230 V across the load. (i) Find the high-side terminal voltage for a load power factor of 0.85 lagging. (ii) Find the high-side terminal voltage for a load power factor of 0.85 leading.
c. Consider a rated-kVA load connected at the low-voltage terminals operating at 240V. Use MATLAB to plot the high side terminal voltage as a function of the power-factor angle as the load power factor varies from 0.6 leading through unity power factor to 0.6 pf lagging.

PROBLEM 14.

A single-phase load is supplied through a 35-kV feeder whose impedance is $95 + j360\ \Omega$ and a 35-kV:2400-V transformer whose equivalent impedance is $(0.23 + j1.27)\ \Omega$ referred to its low-voltage side. The load is 160 kW at 0.89 leading power factor and 2340 V.

a. Compute the voltage at the high-voltage terminals of the transformer.
b. Compute the voltage at the sending end of the feeder.
c. Compute the power and reactive power input at the sending end of the feeder.

PROBLEM 15.

The following data were obtained for a 20-kVA, 60-Hz, 2400:240-V distribution transformer tested at 60 Hz:

	Voltage, V	Current, A	Power, W
With high-voltage winding open-circuited	240	1.038	122
With low-voltage terminals short-circuited	61.3	8.33	257

a. Compute the efficiency at full-load current and the rated terminal voltage at 0.8 power factor.

Assume that the load power factor is varied while the load current and secondary terminal voltage are held constant. Use a phasor diagram to determine the load power factor for which the regulation is greatest. What is this regulation?

PROBLEM 16.

A three-phase generator step-up transformer is rated 26-kV:345-kV, 850 MVA and has a series impedance of $0.0035 + j0.087$ per unit on this base. It is connected to a 26-kV, 800-MVA generator, which can be represented as a voltage source in series with a reactance of $j1.57$ per unit on the generator base.

(a) Convert the per unit generator reactance to the step-up transformer base.
(b) The unit is supplying 700 MW at 345 kV and 0.95 power factor lagging to the system at the transformer high-voltage terminals.
    (i) Calculate the transformer low-side voltage and the generator internal voltage behind its reactance in kV.
    (ii) Find the generator output power in MW and the power factor.

SOLUTION OF PROBLEM 1.

Now, $e_M = M dI_1/dt$

$$M = \frac{e_M}{dI_1/dt} = \frac{11.25}{1500} = 7.5\times10^{-3}\,H = \mathbf{7.5\ mH}$$

Now $L_1 = \dfrac{N_1\Phi_1}{I_1}$ $\therefore \dfrac{\Phi_1}{I_1} = \dfrac{L_1}{N_1} = \dfrac{15\times10^{-3}}{750} = 2\times10^{-5}$ Wb/A

Now $k = \dfrac{M}{\sqrt{L_1L_2}} = \dfrac{7.5\times10^{-3}7.5\times10^{-3}}{15\times10^{-3}} = 0.5 = 50\%$ $(\because L_1 = L_2 = L)$

SOLUTION OF PROBLEM 2.

(i) Flux/ampere in A =0.6/5=0.12 mWb

Flux linked with B $= 0.12\times0.6 = 0.072$ mWb

$$M = 0.072\times10^{-3}\times16{,}000 = \mathbf{1.15\ H}$$

Now $L_1 = \dfrac{12{,}500\times0.6}{5} = 150\times10^{-3}\,H$; $L_2 = \dfrac{16{,}000\times0.8}{5} = 256\times10^{-3}\,H$

(ii) $k = M/\sqrt{L_1L_2} = 1.15/\sqrt{1.5\times2.56} = \mathbf{0.586}$

Note. We could find k in another way also. Value of $k_1 = 0.6$, that of k_2 could also be found, then $k = \sqrt{k_1k_2}$

SOLUTION OF PROBLEM 3.

$M = 32\times10^{-3}$ H; $dI_1 = 15-3 = 12$ m A $= 12\times10^{-3}$ A; dt =0.004 second

Average e.m.f. induced $= M\dfrac{dI_1}{dt} = \dfrac{32\times10^{-3}\times12\times10^{-3}}{0.004} = 96\times10^{-3}$ V

Now $L_1 = \mu_0N^2A/l = kN^2$ where $k = \mu_0A/l$ (taking $\mu_r = 1$)

$$L_2 = \frac{(2N)^2\mu_0A}{2l} = 2kN^2 \;;\; \frac{L_2}{L_1} = \frac{2kN^2}{kN^2} = 2 \quad \therefore L_2 = 2L_1$$

Now $M = \sqrt{L_1L_2} = \sqrt{2L_1\times L_1} = 32$, $L_1 = 32/\sqrt{2} = 16\sqrt{2}$ **m H**; $L_2 = 2\times16\sqrt{2} = 32\sqrt{2}$ **m H**.

SOLUTION OF PROBLEM 4.

(i) $M = \dfrac{\textit{flux-linkages of coil B}}{\textit{current in coil A}} = \dfrac{100\times10^{-6}}{1} = 100\mu$ **H**

(ii) $M = k\sqrt{L_1L_2}$ $\therefore k = \dfrac{M}{\sqrt{L_1L_2}} = \dfrac{100\times10^{-6}}{\sqrt{120\times10^{-6}\times300\times10^{-6}}} = \mathbf{0.527}$

(iii) $e_2 = M\times di/dt = (100\times10^{-6})\times2/0.1 = 0.002V$ or **2 m V.**

SOLUTION OF PROBLEM 5.

(a) $L = L_1 + L_2 + 2M$ or $1.9 = L_1 + L_2 + 2M$ ...(i)

(b) Here $L = L_1 + L_2 - 2M$ or $0.7 = L_1 + L_2 - 2M$ ...(ii)

Substracting (ii) from (i), we get

$1.2 = 4M \quad \therefore \quad M = 0.3\,\text{H}$

Putting this value in (i) above, we get $L_1 + L_2 = 1.3\,\text{H}$ ...(iii)

We know that, in general, $M = k\sqrt{L_1L_2}$

$\therefore \quad \sqrt{L_1L_2} = \dfrac{M}{k} = \dfrac{0.3}{0.5} = 0.6 \qquad \therefore \quad L_1L_2 = 0.36$

From (iii), we get $(L_1 + L_2)^2 - 4L_1L_2 = (L_1 - L_2)^2$

$\therefore \quad (L_1 - L_2)^2 = 0.25$ or $L_1 - L_2 = 0.5$ ...(iv)

From (iii) and (iv), we get $L_1 = \mathbf{0.9\ H}$ and $L_2 = \mathbf{0.4\ H}$

SOLUTION OF PROBLEM 6.

(i) $L = L_1 + L_2 + 2M$ or $0.6 = L_1 + L_2 + 2M$ ...(i)

and $0.1 = L_1 + L_2 - 2M$ ...(ii)

(a) From (i) and (ii) we get, $M = \mathbf{0.125\ H}$

Let $L_1 = 0.2\,\text{H}$, then substituting this value in (i) above, we get $L_2 = 0.15\,\text{H}$

(b) Coupling coefficient $k = M/\sqrt{L_1L_2} = 0.125/\sqrt{0.2 \times 0.15} = \mathbf{0.72}$

SOLUTION OF PROBLEM 7.

If each coil has an inductance of L henry, then $L_1 = L_2 = L$; $M = k\sqrt{L_1L_2} = k\sqrt{L \times L} = kL$

When connected in series cumulatively, the total inductance of the coils is

$= L_1 + L_2 + 2M = 2L + 2M = 2L + 2kL = 2L(1 + 0.25) = 2.5L$

$\therefore \quad 2.5L = 80$ or $\text{L} = \mathbf{32\ m\,H}$

When connected in series differentially, the total inductance of the coils is

$= L_1 + L_2 - 2M = 2L - 2M = 2L - 2kL = 2L(1 - k) = 2L(1 - 0.25)$

$\therefore \quad 2L \times 0.75 = 2 \times 32 \times 0.75 = \mathbf{48\ m\,H}$

SOLUTION OF PROBLEM 8.

$L_1 = 1200\,\text{m H}$, $L_2 = 800\,\text{m H}$

Fig. 7.15 (a) shows additive series.

$\therefore \quad L = L_1 + L_2 + 2M$

or $2500 = 1200 + 800 + 2M$; $M = \mathbf{250\ m\,H}$

Fig. 7.15 (b) shows the case of subtractive or opposing series.

Here, $L = L_1 + L_2 - 2M = 1200 + 800 - 2 \times 250 = \mathbf{1500\ m\,H}$

SOLUTION OF PROBLEM9.

(a) Combined inductance is given by $L = L_1 + L_2 \pm 2M$

$\therefore \quad 0.5 = L_1 + L_2 + 2M$ ...(i) , $0.2 = L_1 + L_2 - 2M$ ...(ii)

Subtracting (ii) from (i), we have 4M = 0.3 or $M = \mathbf{0.075\ H}$

(b) Adding (i) and (ii) we have $0.7 = 2 \times 0.2 + 2L_2$; $L_2 = \mathbf{0.15\ H}$

(c) Coupling factor or coefficient is $k = M/\sqrt{L_1L_2} = 0.075/\sqrt{0.2 \times 0.15} = 0.433$ or **43.3%**.

(d) $e_1 = L_1 \frac{di}{dt} \pm M \frac{di}{dt}$

$\therefore$ $e_1 = (0.2 + 0.075) \times 1000 = \mathbf{275\ V}$

$= (0.2 - 0.075) \times 1000 = \mathbf{125\ V}$

SOLUTION OF PROBLEM 10.

(i) $$L = \frac{L_1 L_2 - M^2}{L_1 + L_2 - 2M} = \frac{4 \times 6 - 3^2}{4 + 6 - 2 \times 3} = \frac{15}{4} = \mathbf{3.75\ H}$$

(ii) $$L = \frac{L_1 L_2 - M^2}{L_1 + L_2 + 2M} = \frac{24 - 9}{16} = \frac{15}{16} = \mathbf{0.94\ H\ (approx.)}$$

SOLUTION OF PROBLEM 11.

For maximum power transfer, the load resistance (referred to the primary) must be equal to the source resistance.

$$R_L' = \left(\frac{N_1}{N_2}\right)^2 R_L = n^2 R_L = 2000 \Rightarrow n = \sqrt{\frac{2000}{50}} = 6.32$$

The primary current: $I_1 = \frac{V_s}{2R_s}$ $\Rightarrow$ Power supplied to the load: $P_{load} = R_L' I_1^2 = R_s \frac{V_s^2}{4R_s^2} = \frac{V_s^2}{4R_s} = 8\ \text{mW}$

For a general turns ratio n: $I_1 = \frac{V_s}{R_s + R_L'} = \frac{V_s}{R_s + n^2 R_L}$ $\Rightarrow$ $P_{load} = R_L' I_1^2 = n^2 R_L \left(\frac{V_s}{R_s + n^2 R_L}\right)^2$

SOLUTION OF PROBLEM 12.

Secondary current: $I_2 = \frac{P_{load}}{V_{load}} = \frac{25000}{450} = 55.55\ \text{A}$ $\Rightarrow$ Primary current $I_1 = \frac{460}{2400} \times 55.55 = 10.65\ \text{A}$

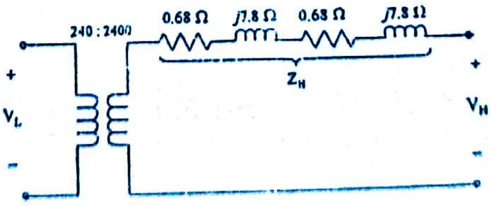
Primary voltage: $V_1 = (j37.2) I_1 + V_2'$ $\quad V_2' = \frac{2400}{460} \times 450 = 2347.8\ \text{V}$

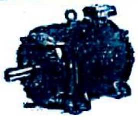
$$\Rightarrow V_1 = (j37.2) I_1 + V_2' = (j37.2) \times 10.65 + 2347.8 = 2347.8 + j396.18 = 2381.0\angle 9.58^\circ\ \text{V}$$

Power factor at primary terminals: $\cos(9.58^\circ) = 0.9861$ lagging.

SOLUTION OF PROBLEM 13.

(a)
(i) referred to the HV side





(b) Load current referred to the HV side: $I'_{load} = I_{feed} = \frac{2.4}{35} \times 76.83\angle 27.13^\circ = 5.2683\angle 27.13^\circ$ A

$$V_{send} = Z_f I_{feed} + V_H = (95 + j360) \times 5.2683\angle 27.13^\circ + 3371 + j1384 = 33.286 + j3.3 \text{ kV}$$

$$|V_{send}| = 33.45 \quad \text{kV}$$

SOLUTION OF PROBLEM 15.

(a) Rated current on the HV side = 20 kVA / 2400 = 8.33 A. Therefore, total power loss at full load current:
P_L= 122 + 257 = 379 W. Load power at full load, 0.8 pf = 0.8 × 20 kW = 16 kW. Therefore, input power = 16 + 0.379 = 16.379 kW ⇒ efficiency = (16 / 16.379) × 100% = 97.7 %.

(b) The equivalent impedance of the transformer: $Z_{eq,H} = R_{eq,H} + jX_{eq,H}$

$$R_{eq,H} = \frac{P_{sc}}{I_{sc}^2} = \frac{257}{8.33^2} = 3.7\ \Omega \quad |Z_{eq,H}| = \frac{V_{sc}}{I_{sc}} = \frac{61.3}{8.33} = 7.36\ \Omega$$

$$\Rightarrow \quad X_{eq,H} = \sqrt{(Z_{eq,H})^2 - (R_{eq,H})^2} = 6.36\ \Omega$$

Let load current and voltage referred to the HV side: $V_{lH} = V\angle 0^\circ \quad I_{lH} = I\angle\theta$

$$V_s = V_{lH} + Z_{eq}I_{lH} = V + |Z_{eq}I_{lH}|\angle(\theta + \phi_Z) = V + V_d\angle\alpha \qquad V_d \square |Z_{eq}I_{lH}| \text{ and } \alpha \square \theta + \phi_Z$$

$$= (V + V_d\cos\alpha) + jV_d\sin\alpha$$

$$|V_s| = \sqrt{(V + V_d\cos\alpha)^2 + (V_d\sin\alpha)^2} = \sqrt{V^2 + 2VV_d\cos\alpha + V_d^2}$$

$$\text{Regulation} = \frac{|V_s| - |V_{lH}|}{|V_{lH}|} = \frac{\sqrt{V^2 + 2VV_d\cos\alpha + V_d^2} - V}{V} = \sqrt{1 + \frac{2V_d\cos\alpha}{V} + \frac{V_d^2}{V^2}} - 1$$

Therefore, regulation is maximum when cosα is maximum

$$\Rightarrow \cos\alpha = 1 \quad \Rightarrow \quad \alpha = \theta + \phi_Z = 0 \quad \Rightarrow \quad \theta = -\phi_Z = -\tan^{-1}\left(\frac{X_{eqH}}{R_{eqH}}\right) = -59.81^\circ$$

Maximum regulation:

$$V_d = 7.36 \times 8.33 = 61.31 \text{ V}$$

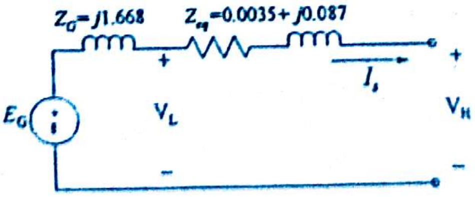
$$\text{When } \alpha = 0^\circ \quad V_s = V + V_d \quad \Rightarrow \quad \text{Regulation} = \frac{V_d}{V} = \frac{61.31}{2400} = 0.026 = 2.6\%$$

SOLUTION OF PROBLEM 16.

(a) On the transformer base

$$X_{gen} = 1.57 \times \left(\frac{850}{800}\right) = 1.668 \text{ pu}$$

(b) Per-unit equivalent circuit:



(i) **Transformer low-side voltage and generator internal voltage:**

$V_{base,H} = 345\text{ kV},\quad V_{base,L} = 26\text{ kV},\quad VA_{base} = 850\text{ MVA}$

$V_H = 1.0\angle 0^\circ$ pu.

$|I_s| = \dfrac{700}{\sqrt{3}\times 345\times 0.95}\text{ kA} = 1.233\text{ kA} \qquad I_{base,H} = \dfrac{VA_{base}}{\sqrt{3}\times V_{base,H}} = \dfrac{850}{\sqrt{3}\times 345}\text{ kA} = 1.4225\text{ kA}$

$|I_s| = \dfrac{1.233}{1.4225} = 0.8668$ pu. $\quad I_s = 0.8668\angle -18.2^\circ$ pu.

OR $\quad P = \dfrac{700}{850} = 0.8235$ pu. $\Rightarrow |I_s|_{pu} = \dfrac{P}{|V_H|_{pu}\cos\theta} = \dfrac{0.8235}{1\times 0.95} = 0.8668$ pu.

$V_L = V_H + (0.0035 + j0.087)I_s = 1.0264 + j0.071$ pu. $= 1.0289\angle 3.94^\circ$

$\Rightarrow |V_L| = 1.0289$ pu. $= 26.75$ kV

$E_G = V_L + (j1.668)I_s = 1.478 + j1.4442$ pu. $= 2.0664\angle 44.34^\circ$ pu. $\quad |E_G| = 26\times 2.0664 = 53.73$ kV

(ii) **Generator output power (at its terminals)**

$S_G = V_L I_s^* = 1.0289\angle 3.94^\circ \times 0.8668\angle 18.2^\circ = 0.8261 + j0.3361$ pu.

$P_G = 0.8261\times 850 = 702.19$ MW

power factor $= \cos(\tan^{-1}\dfrac{0.3361}{0.8261}) = 0.9263$ lagging